Terrestrial laser scanning of the main reflector of the Effelsberg 100 m radio telescope

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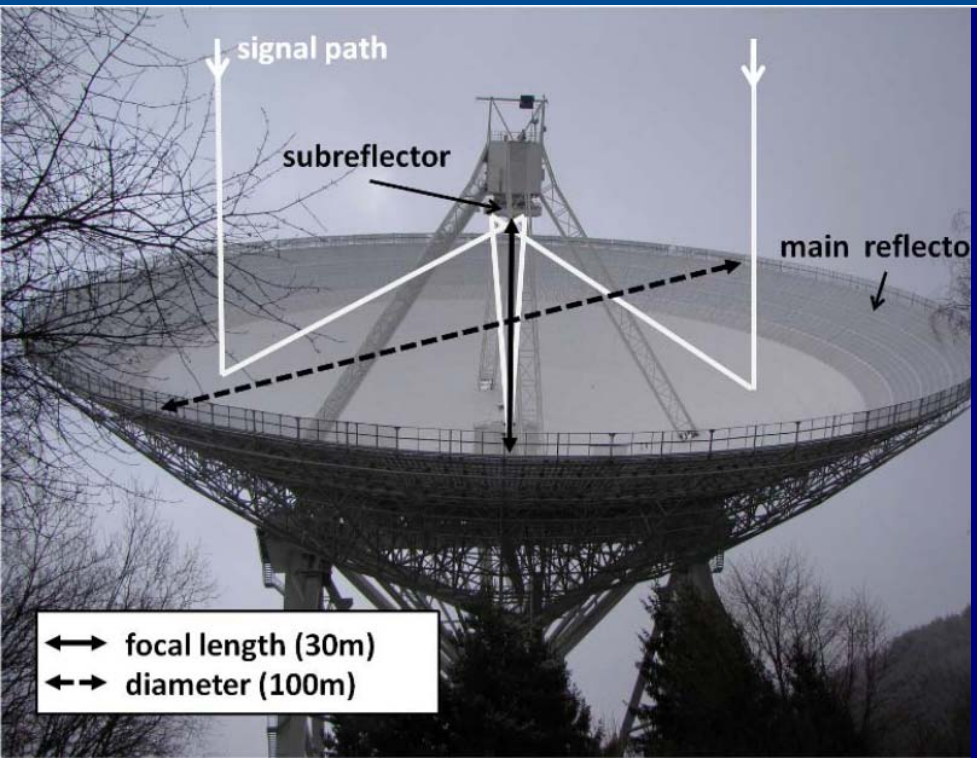
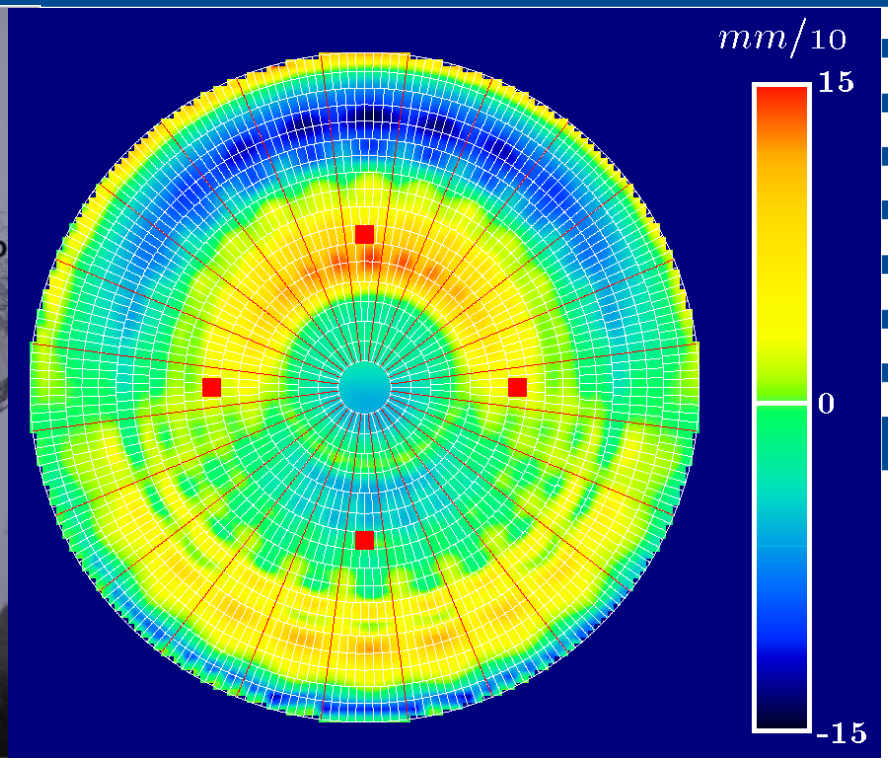
Motivation



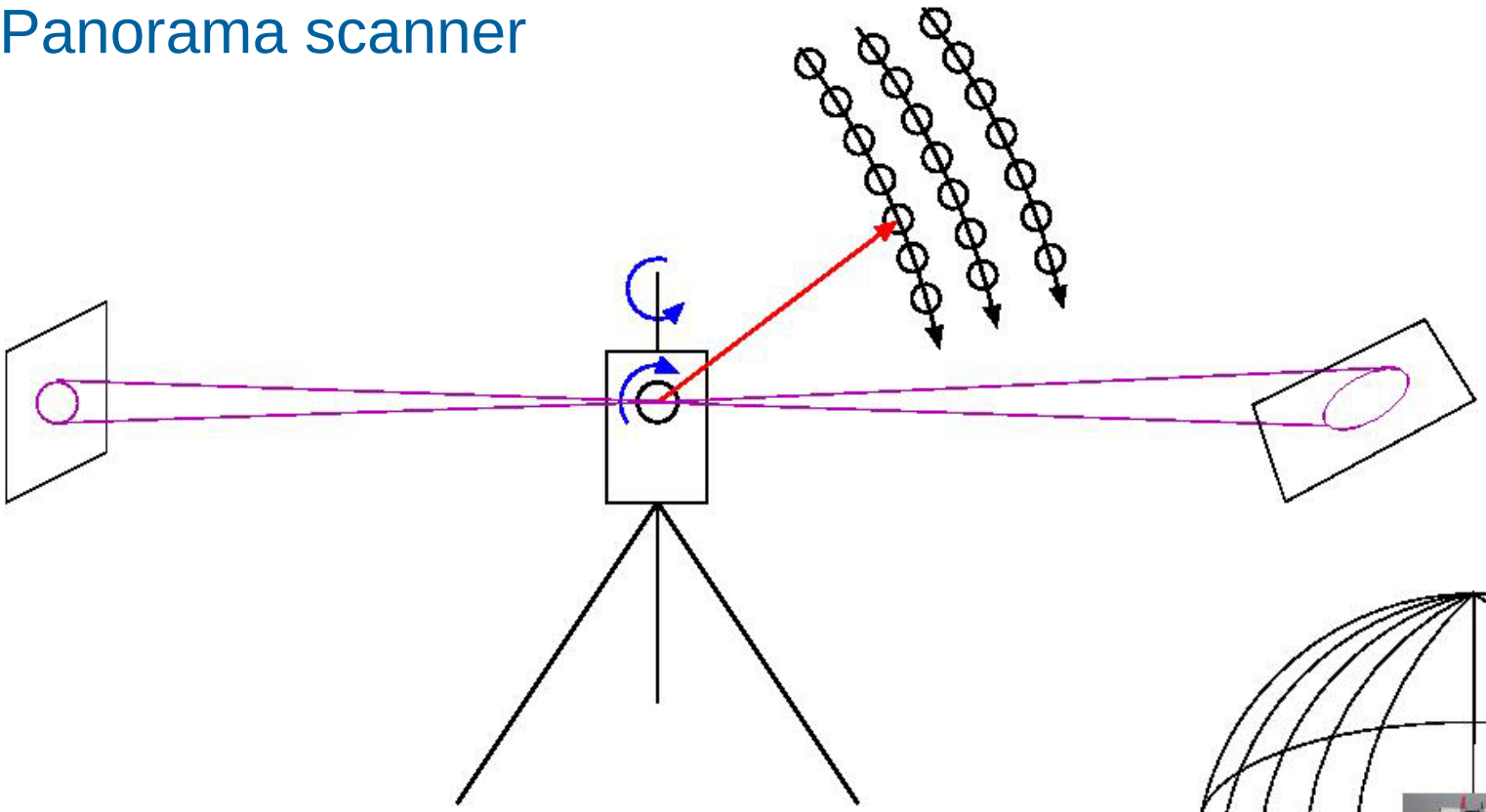


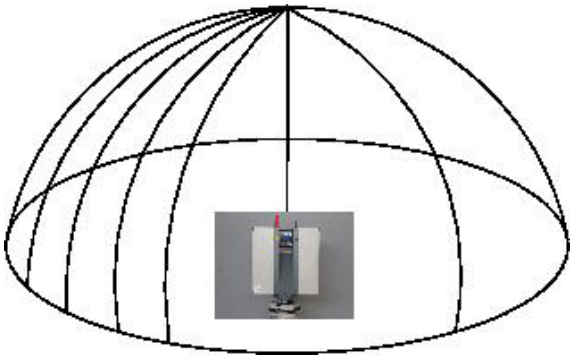
Manufacterer‘s model at 70° elev.,
Courtesy N. Junkes

- Geodesists are interested in gravitationally induced path length variations at different elevation angles
- Astronomers are interested in surface quality

Principles of terrestrial laser scanners

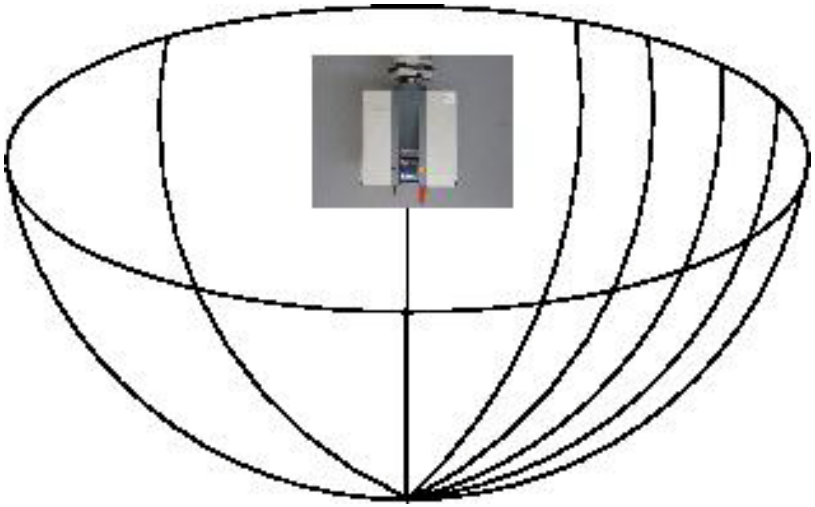
Panorama scanner

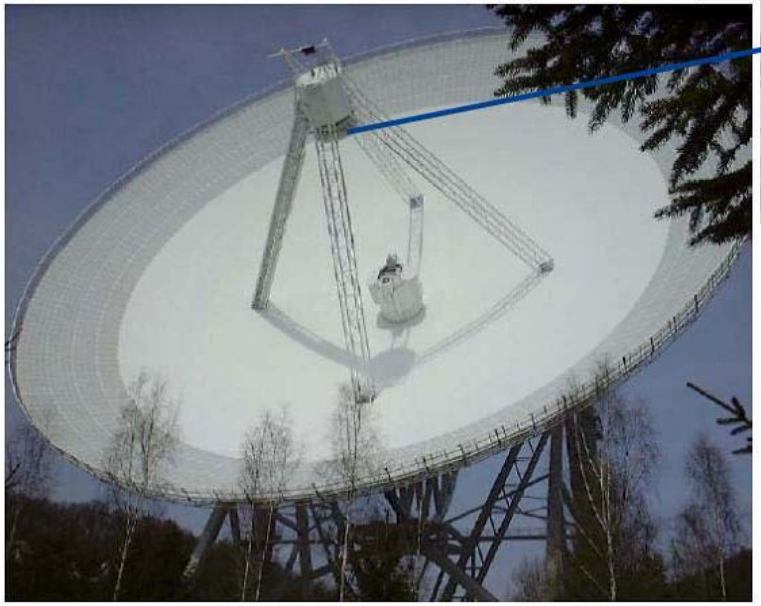




N.B.: Size of footprint depends on angle of incidence
1/cos γ → for γ = 70° → factor of 3

Scanning of radio telescopes





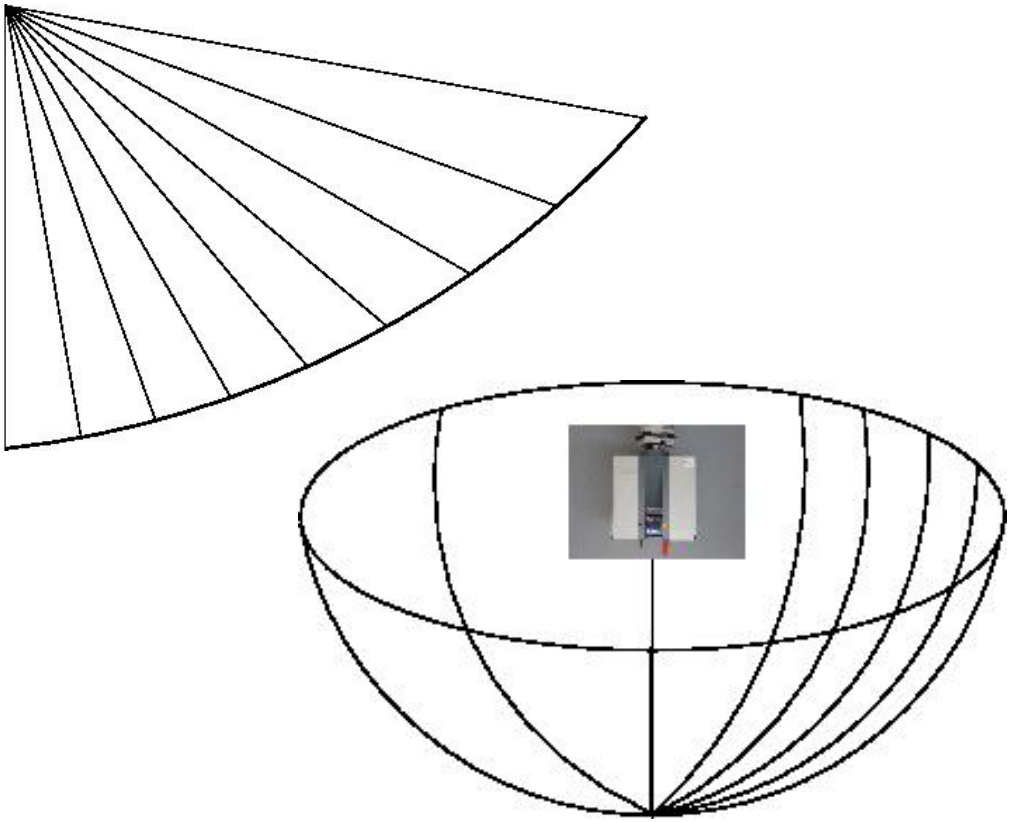
Scanning project 2010

Leica HDS 6100 Terrestrial Laser Scanner

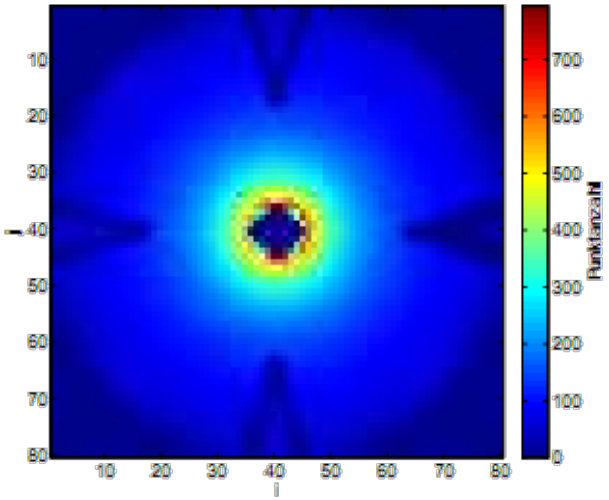
- Scanning in 7 elevations: 90°, 75°, 60°, 45°, 30°, 15°, 7.5°
- Duration: 30 Min per elevation angle
- Spacial resolution: 8 mm x 8 mm (at distance of 50 m)
- Ca. 370 Mio. points per Elevation = 1.11 x 10^9 observations
- Point precision (s = 30 - 50m): 5 – 8 mm
- Size of laser spot (foortprint)
  - 9.6 mm/30 m
  - 14 mm/50 m

Scanning 2010

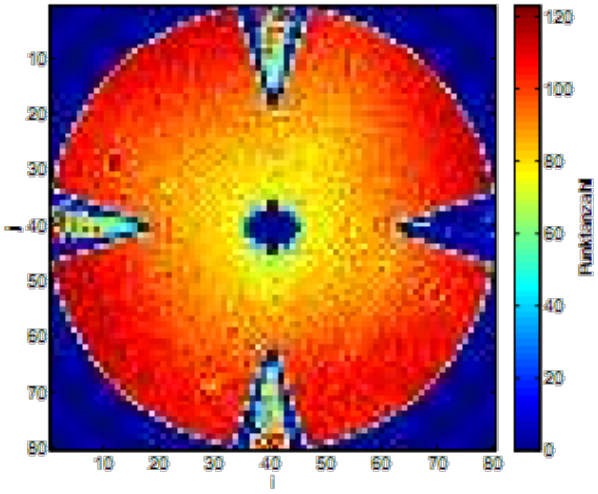
Data decimation



Original point density



Homogeneous point density



Constant angular increments lead to inhomogeneous point densities
→ overweighting of central area
lead to wrong estimates if deformations present in this area

Least squares adjustment

Parameters of rotation paraboloid

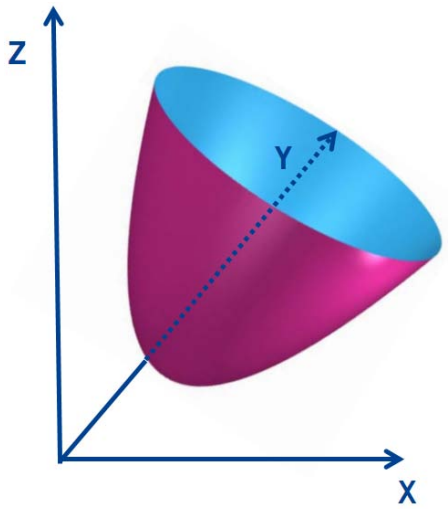
$$g(\mathbf{x}_i^p, \boldsymbol{x}) = \frac{\mathrm{x}_i^2 + \mathrm{y}_i^2}{4f} - \mathrm{z}_i = 0$$

With transformations

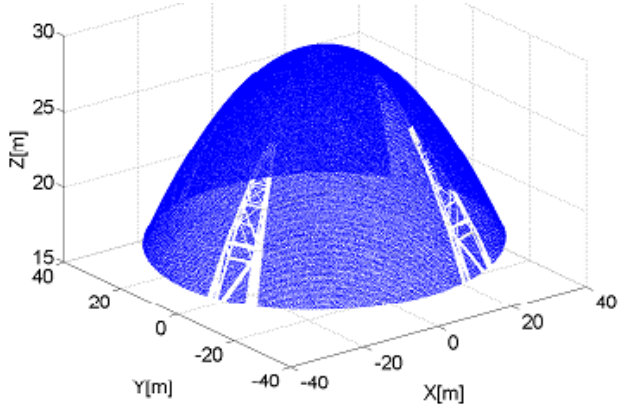
$$\mathbf{x}_i^p = \mathbf{R}_x(\varphi_x) \cdot \mathbf{R}_y(\varphi_y) \cdot \mathbf{x}_i^l - \mathbf{x}_v$$

Parameters of rotational paraboloid

$$\boldsymbol{x} = [\mathrm{x}_v \;\; \mathrm{y}_v \;\; \mathrm{z}_v \;\; \varphi_x \;\; \varphi_y \;\; f]^T$$



- Outer 10m ring not used for parameter estimation (unreliable)
- Outlier elimination (distance threshold)
- Adjustment with Gauß-Helmert-Model
- Cluster,130 GB memory, 4 h per elevation

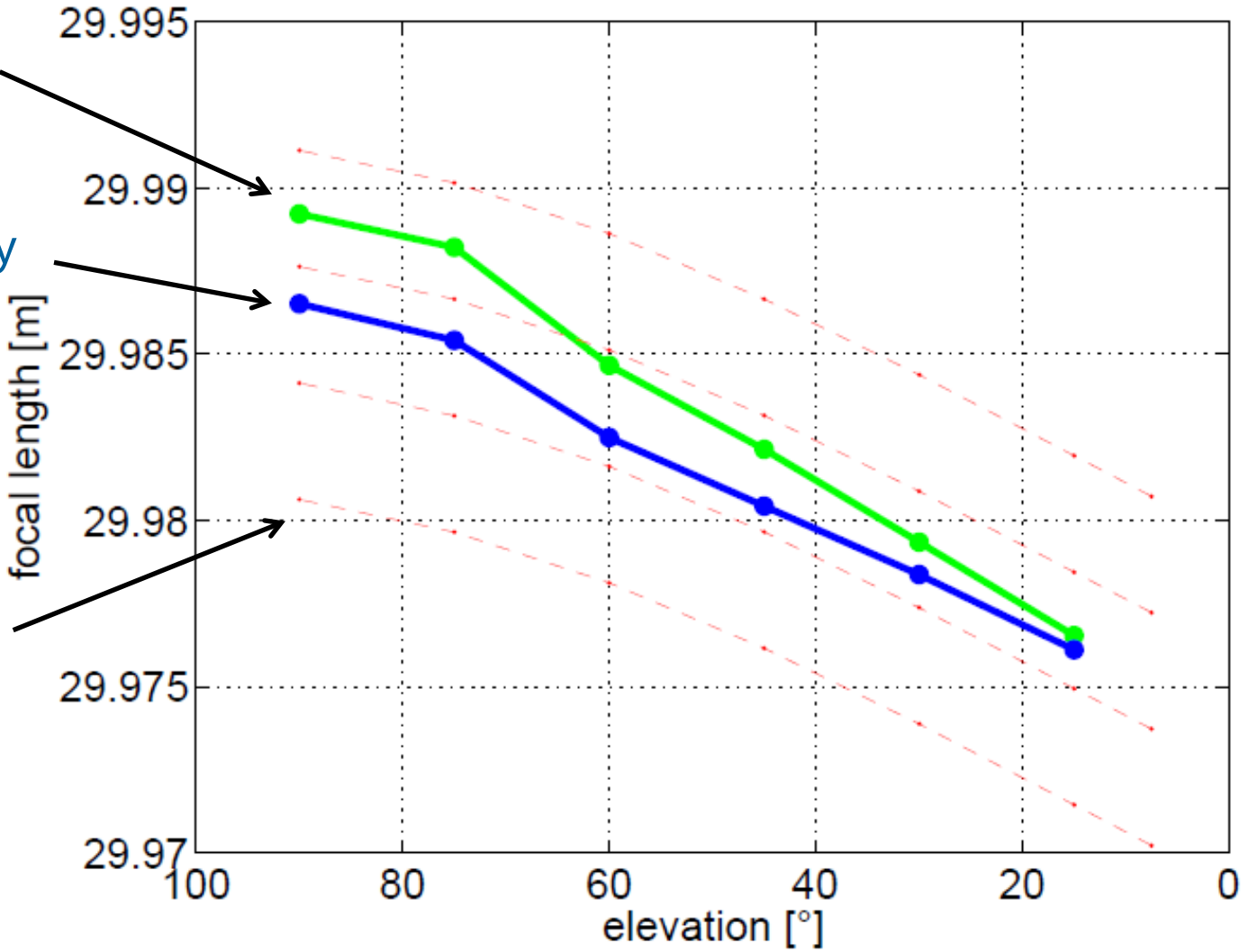


Focal length results

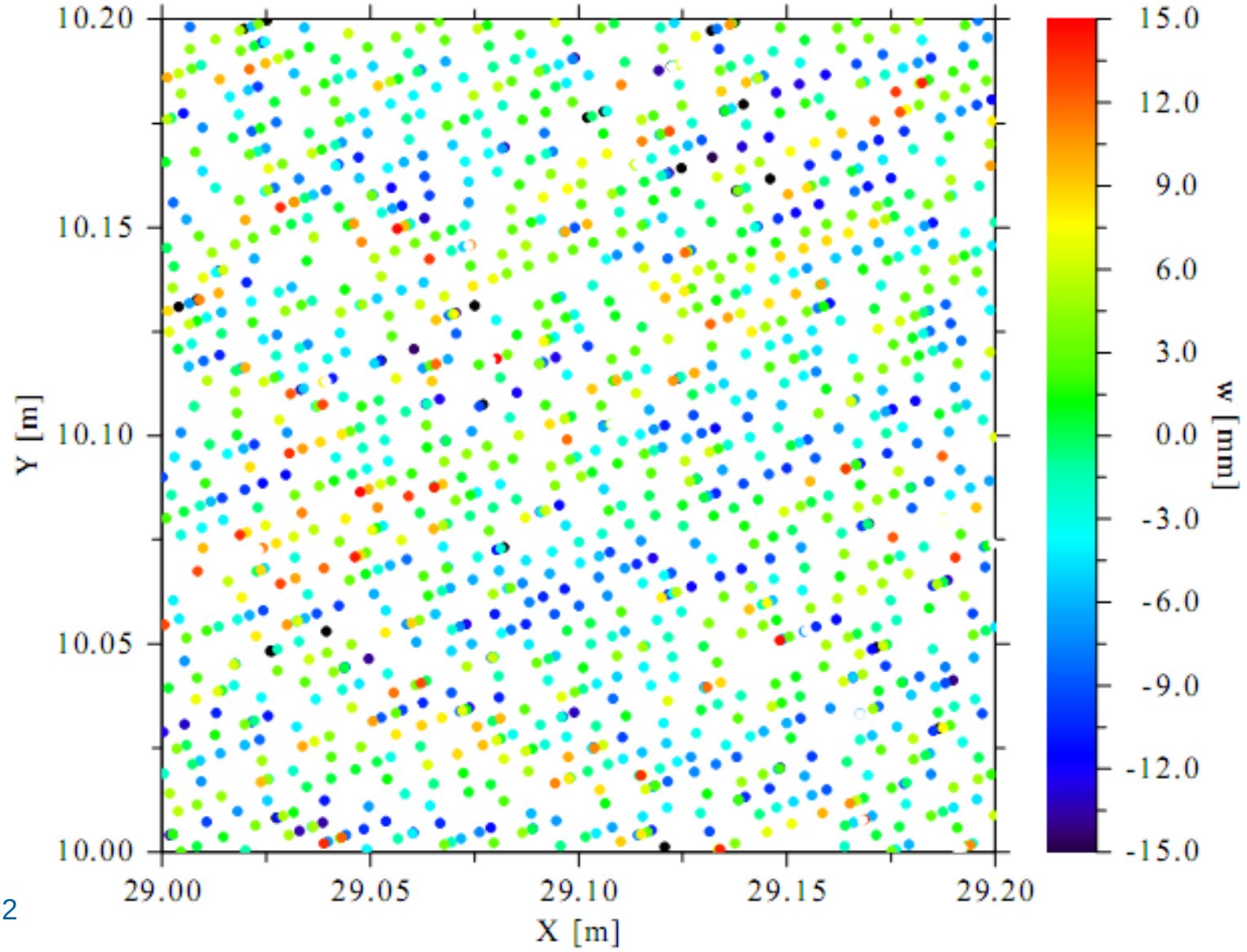
Reduced point density

Full point density

Empirical focus optimization



Individual data points

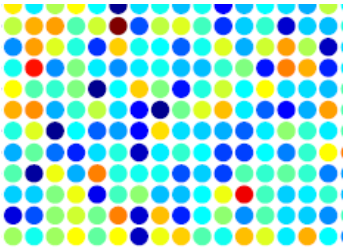


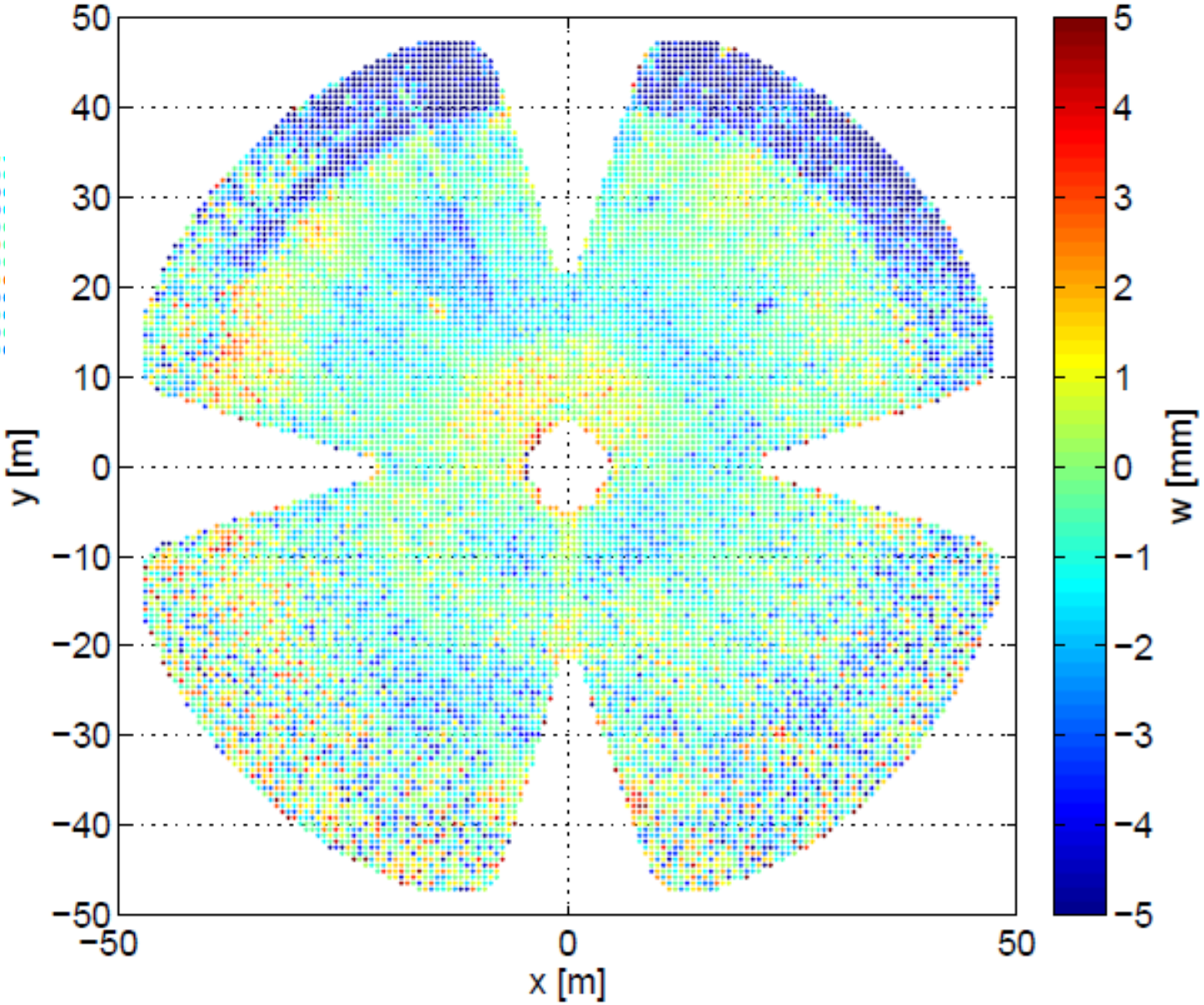
W = C - O

54 lines

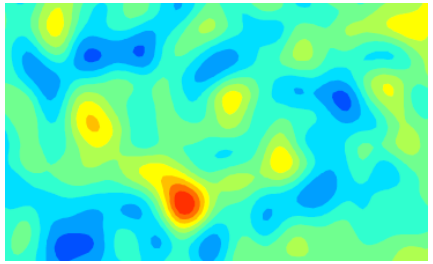
1 pt/64 mm^2

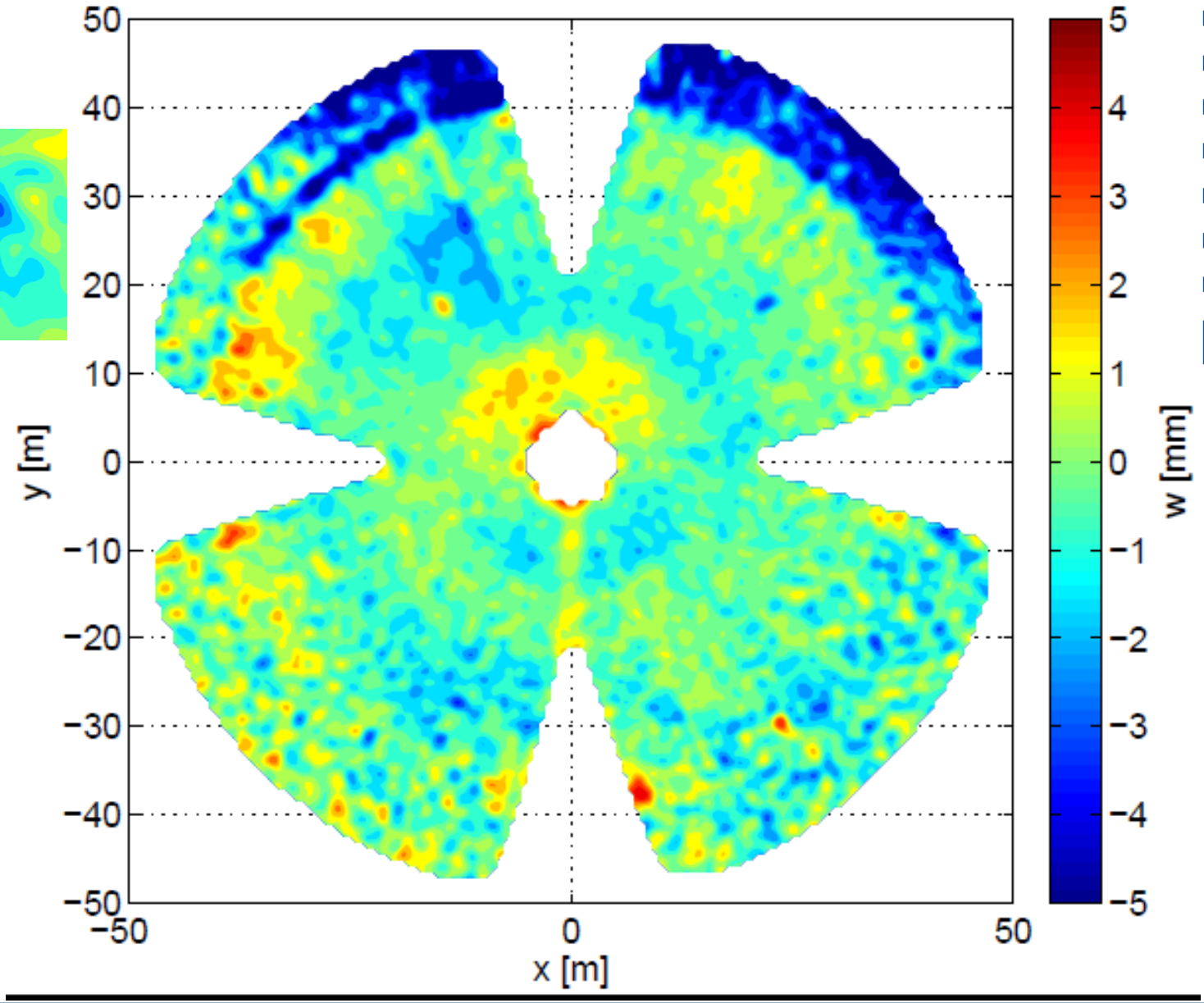
Micro surfaces



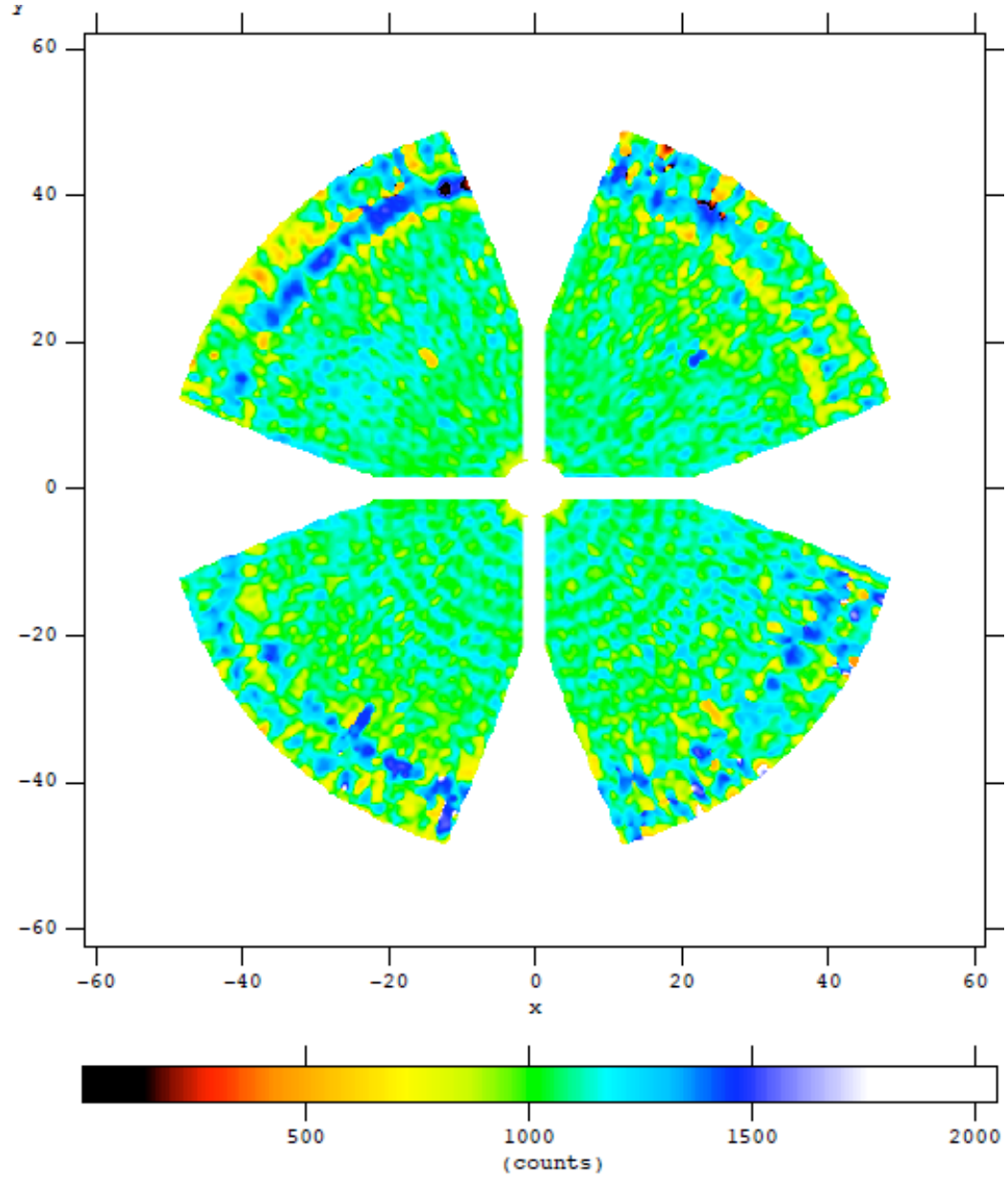


Spline approximations





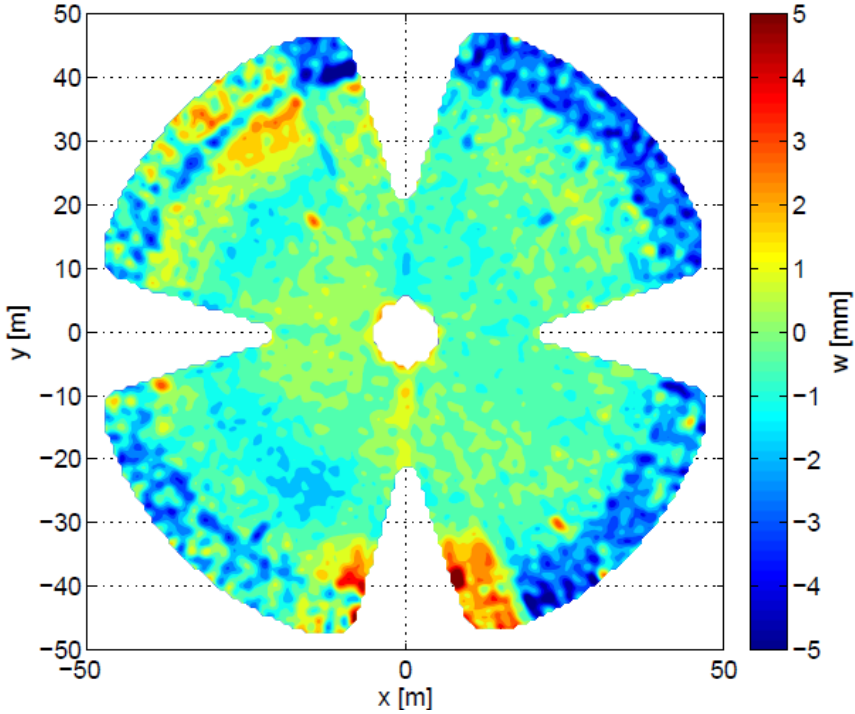
Comparisons



Holography at 32°

Courtesy A. Kraus

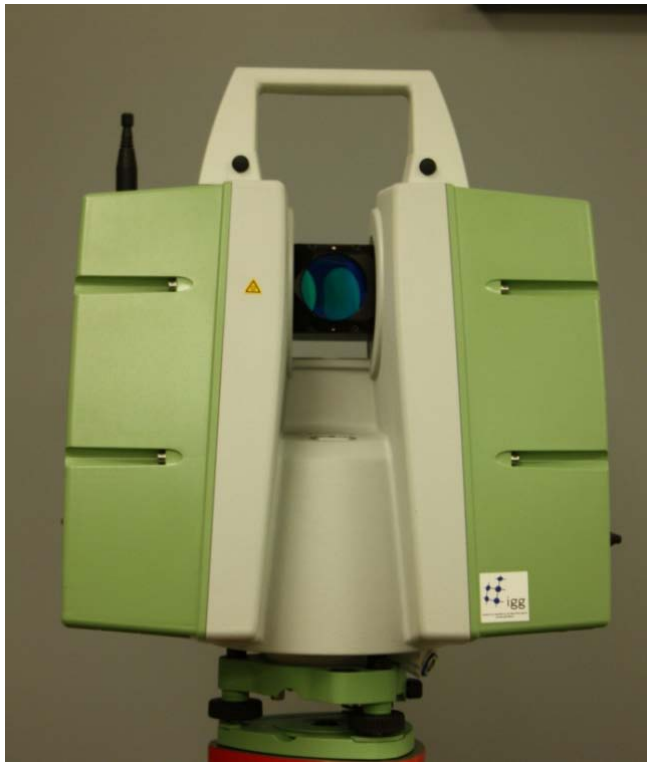
Scanning at 30°



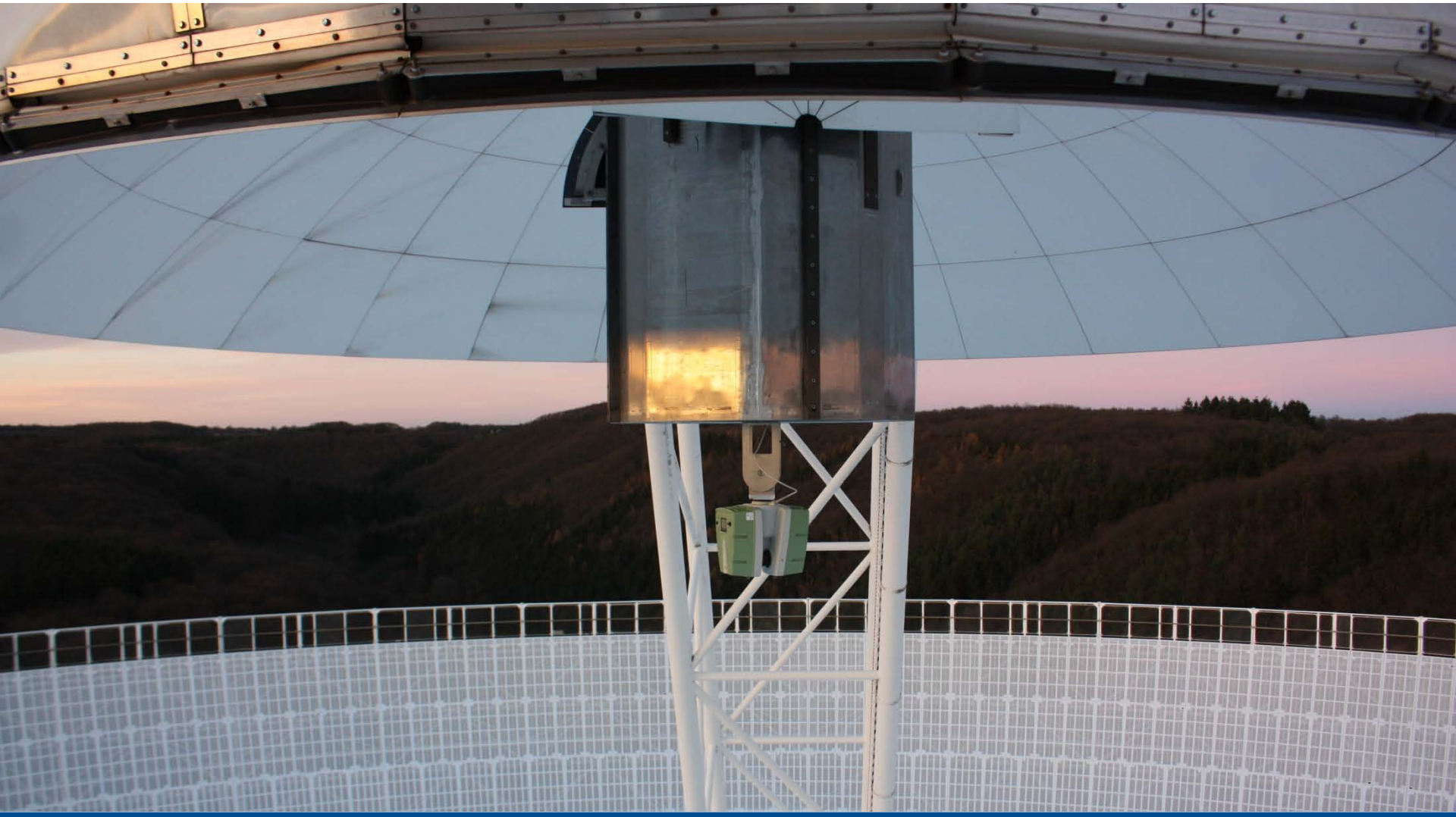
2013 Scanning Project

Leica Scan Station P20

- Scanning in 7 elevations: 90°, 75°, 60°, 45°, 30°, 15°, 7.5°
- Duration: 15 Min per elevation angle
- Spacial resolution: 6 mm x 6 mm (at distance of 50 m)
- Ca. 500 Mio. points per Elevation = 1.5 x 10^9 observations
- Point precision (s = 30 - 50m): 2 – 4 mm
- Size of laser spot (foortprint)
  - 8,8 mm/30 m
  - 12.8 mm/50 m

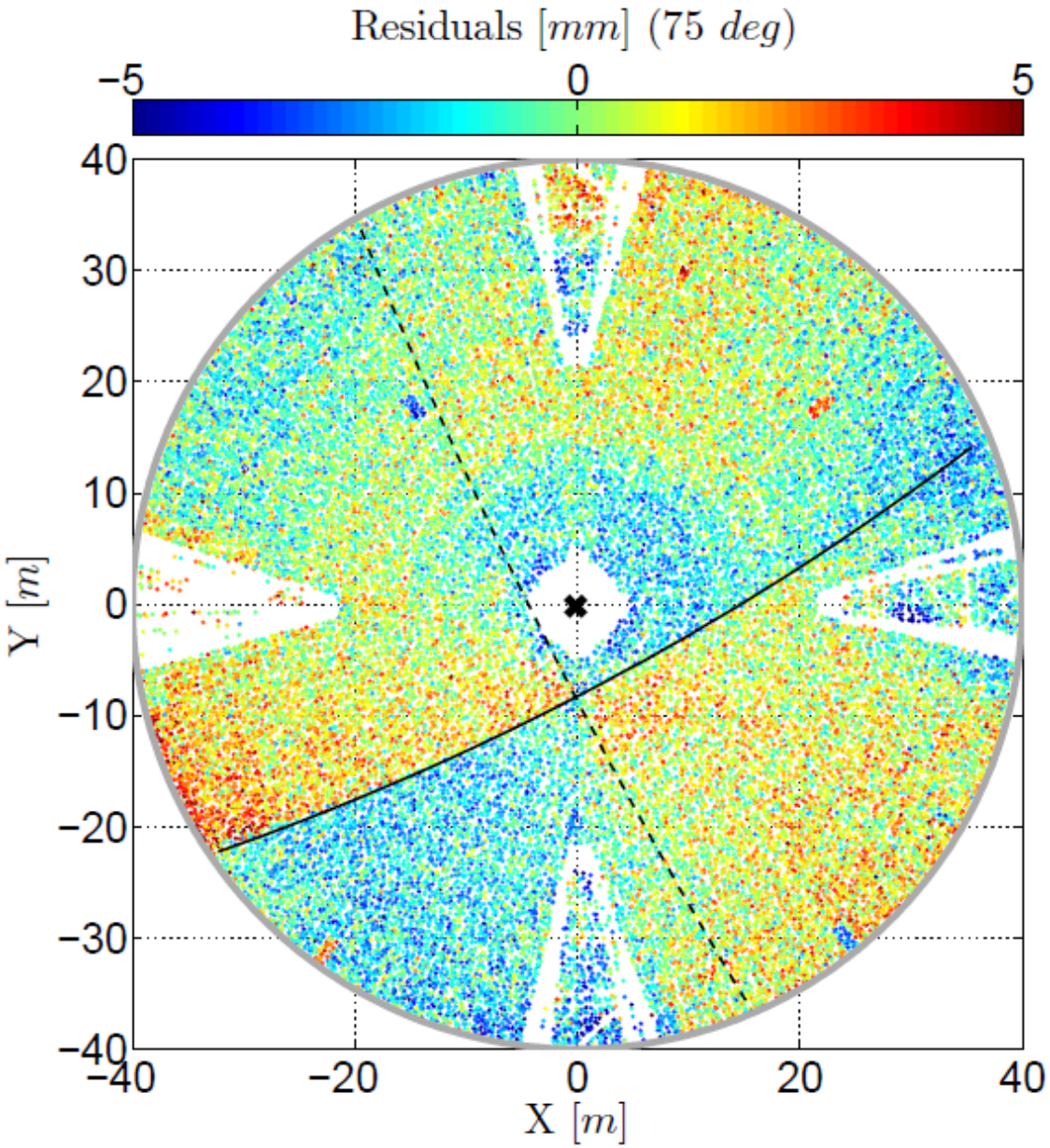


Scanning after sunset



7.5° Elevation

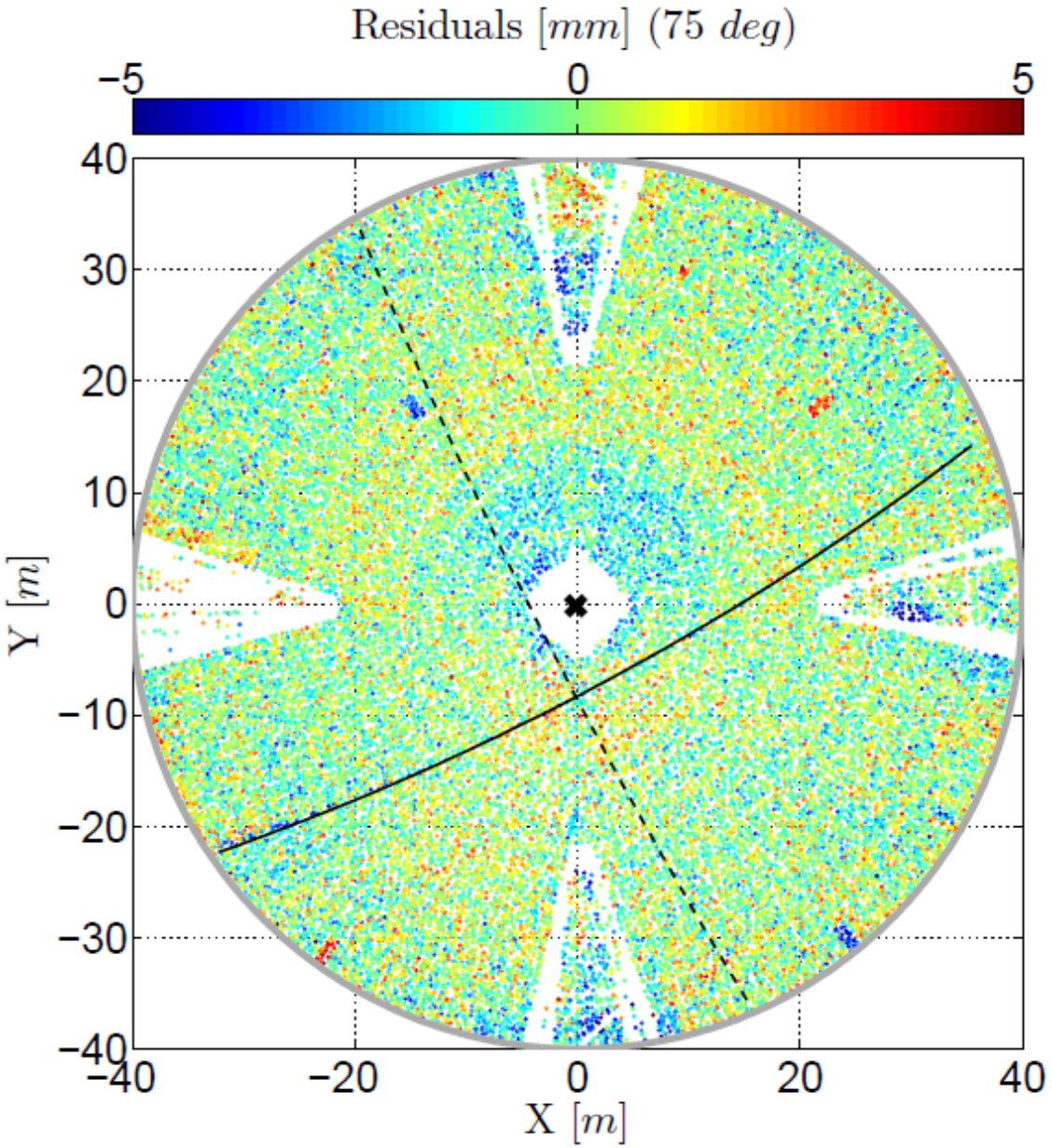
Raw results

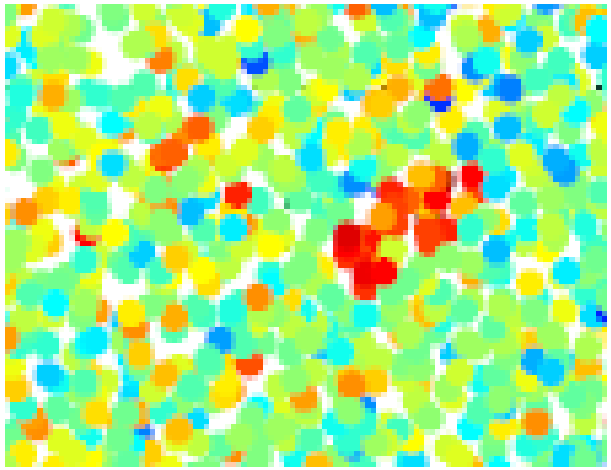


a) Scanner has instrumental errors

b) Estimation of form paramaters depends on data density

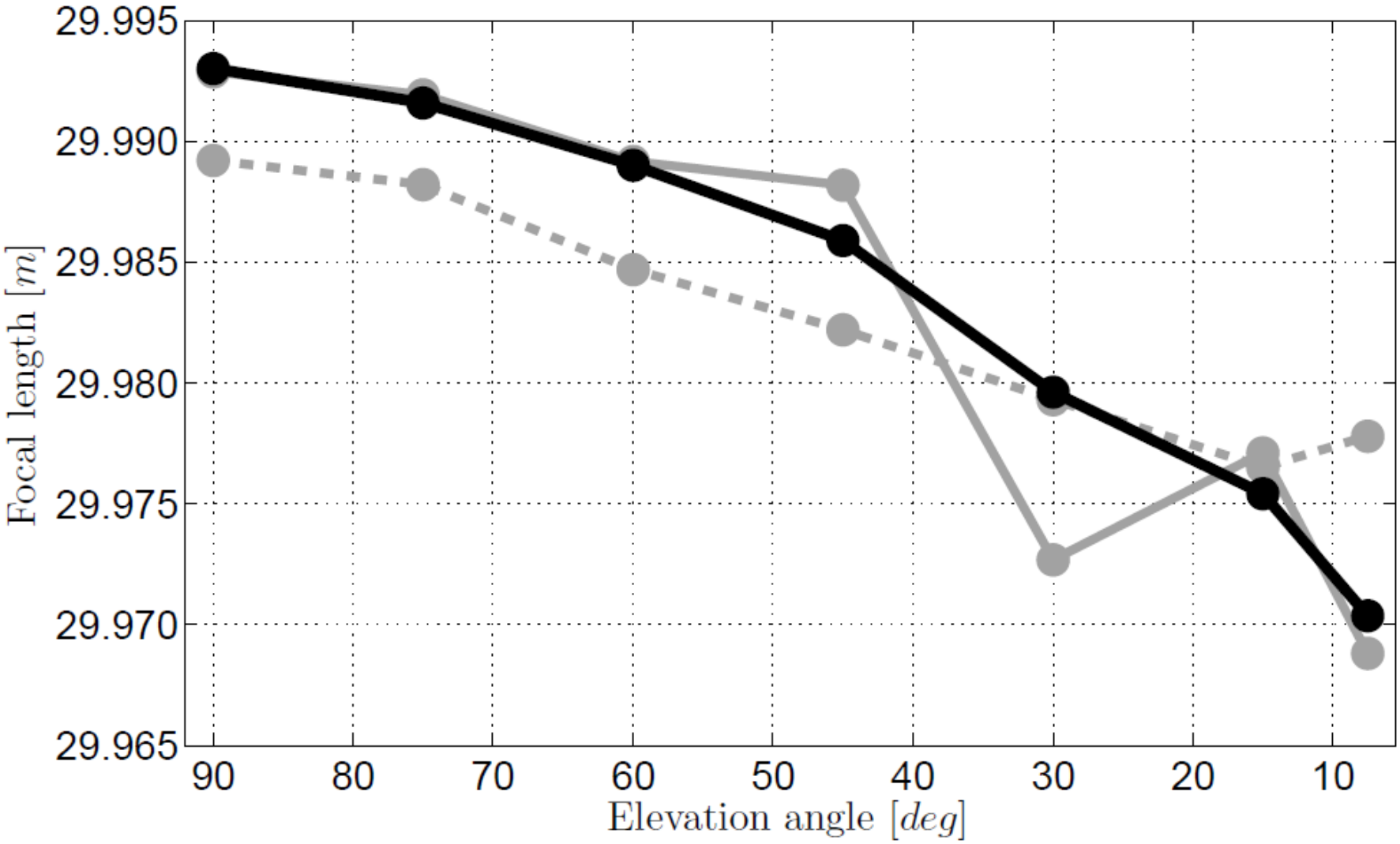
Results after calibrations





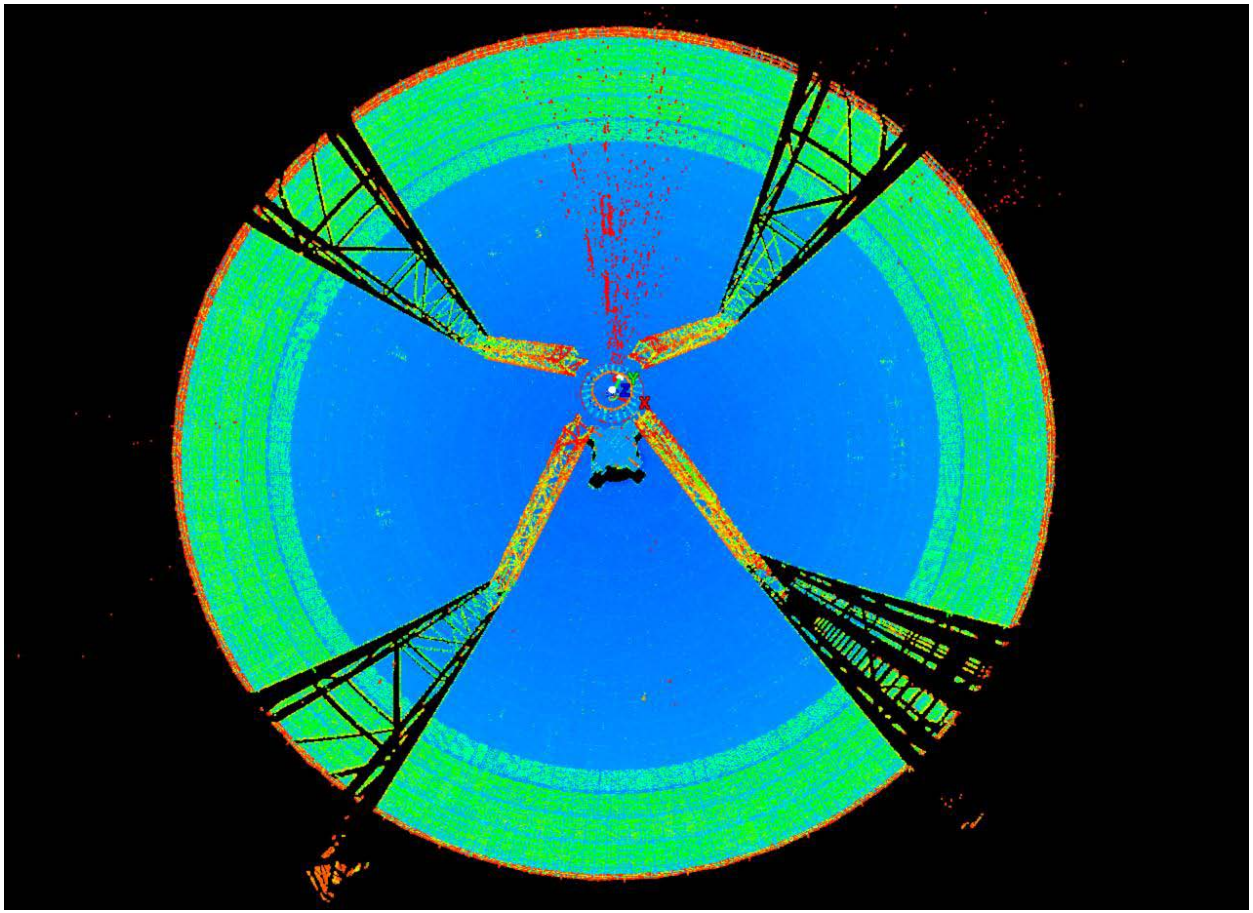
- Data density
- Horizontal collimation error
- Trunnion axis error
- Vertical index error
- Eccentricities of graduated circles
- Eccentricities of axes

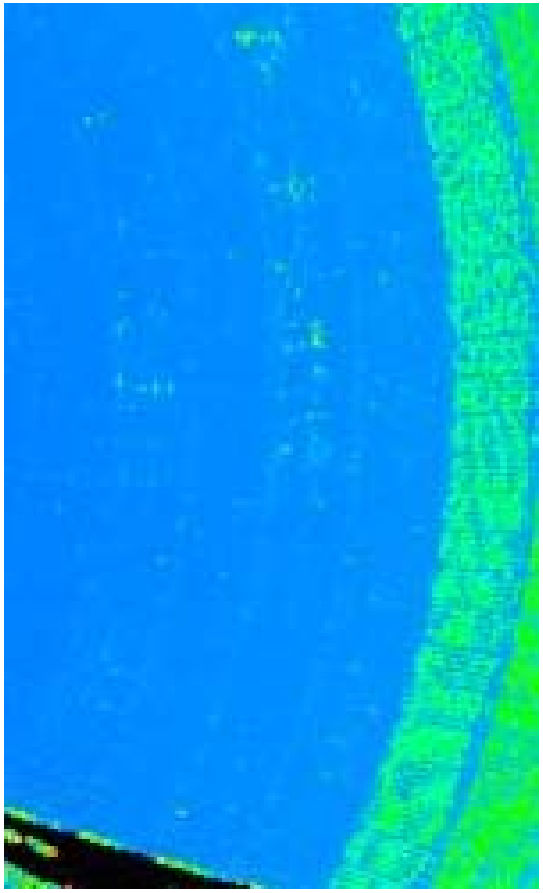
Focal lengths of 2010 and 2013



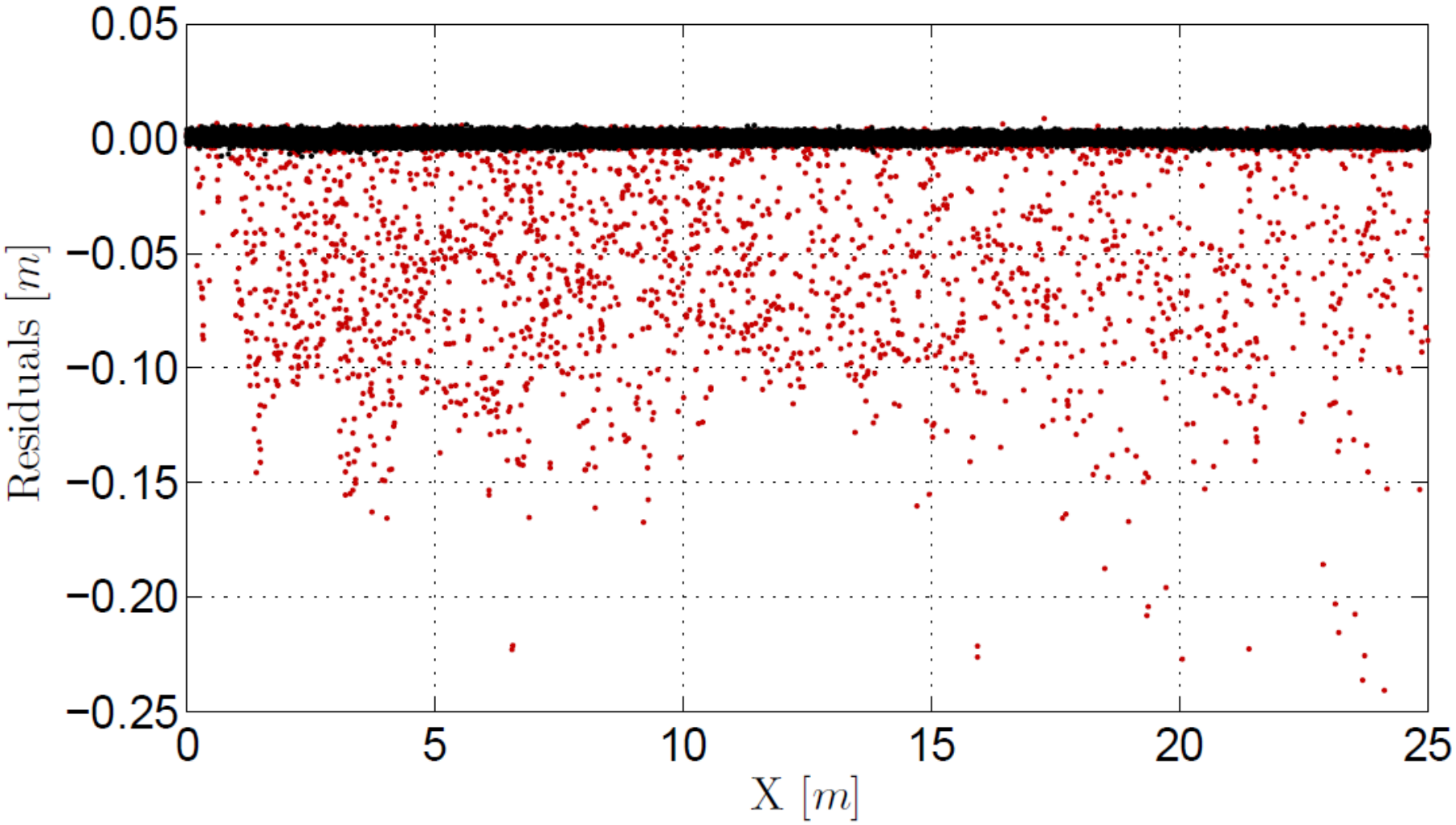
dashed = 2010, grey = 2013 raw, black = 2013 corrected

Reflectivity

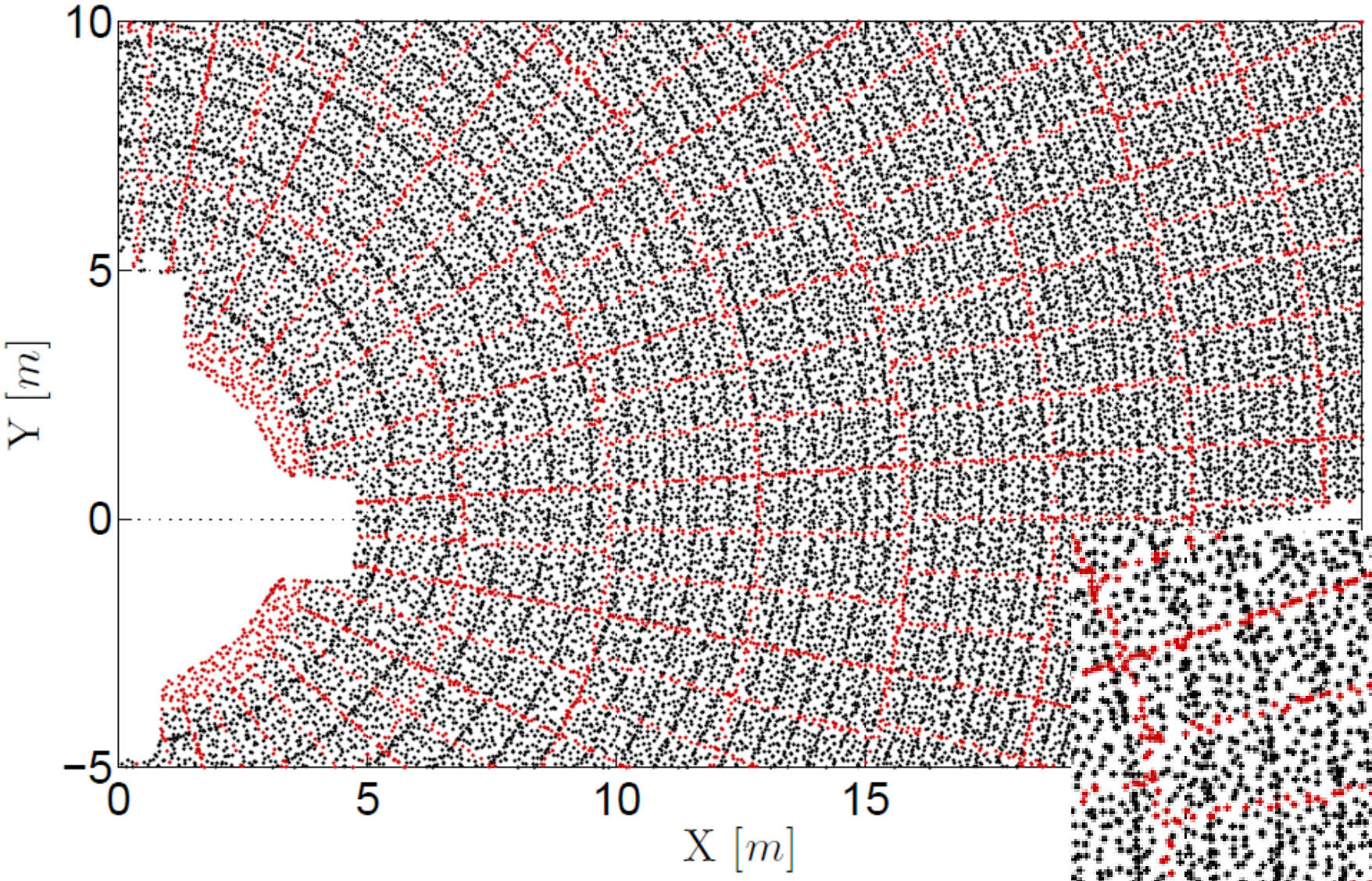




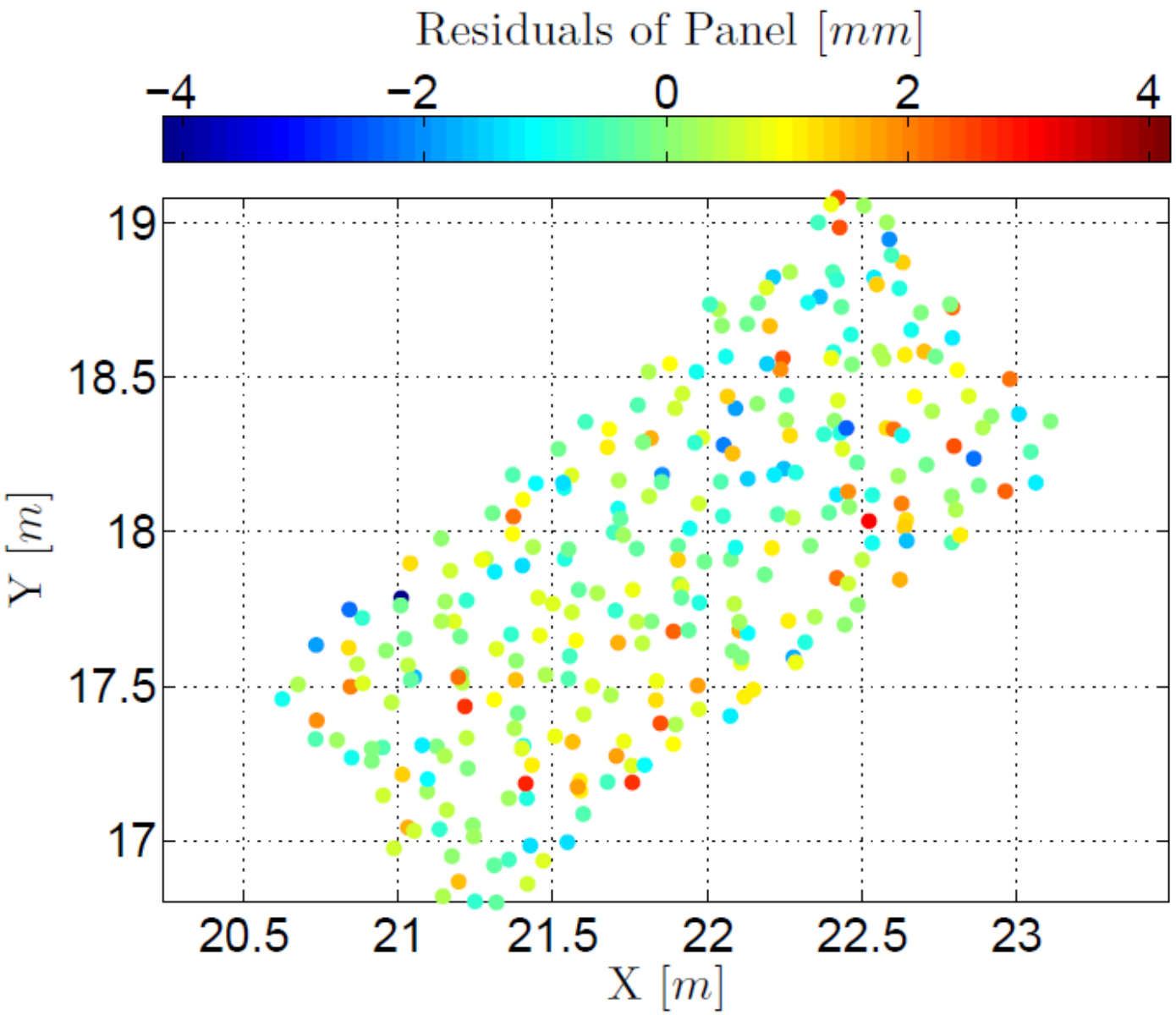
Radial residuals I



Radial residuals II

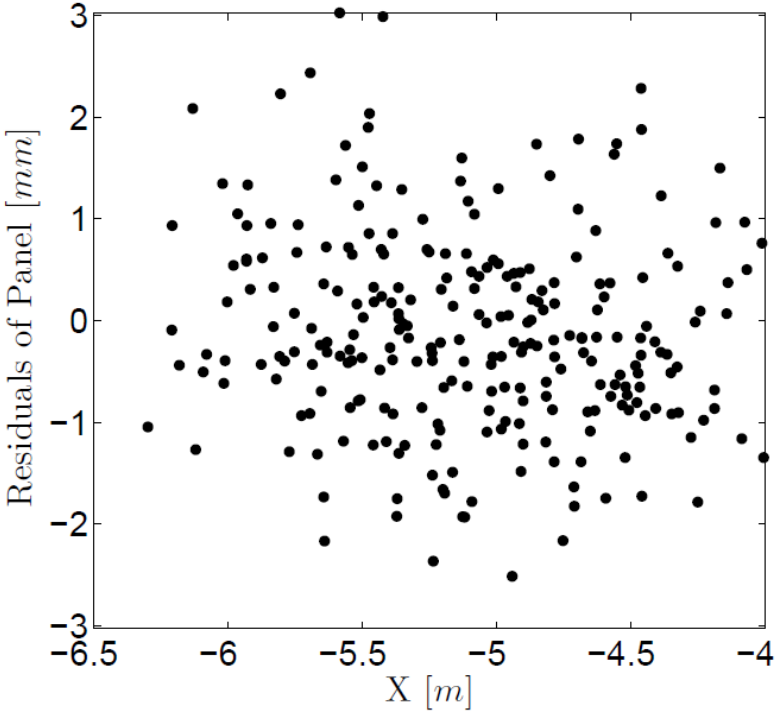


Elev. 60°, Panel 800

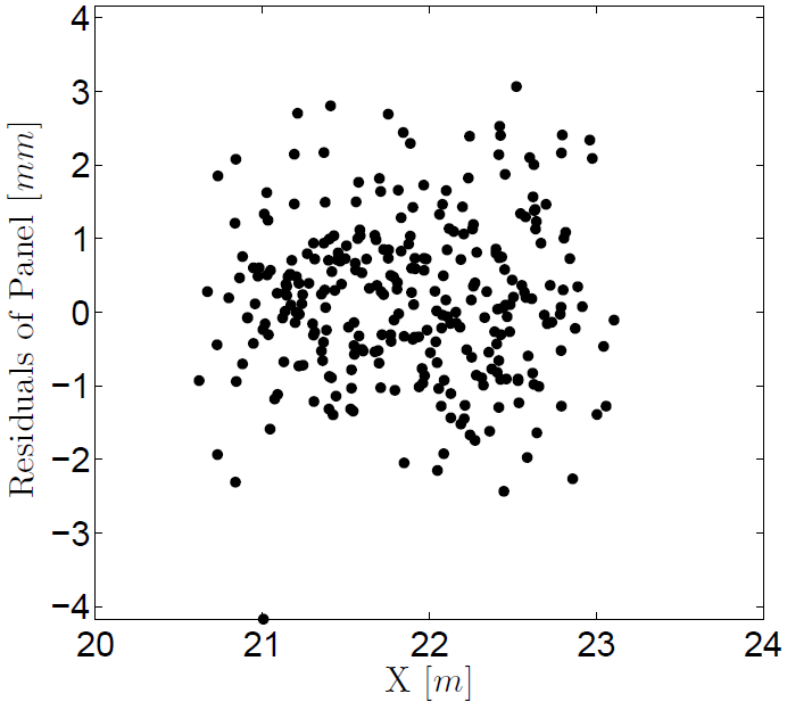


Residuals at elevation 60°

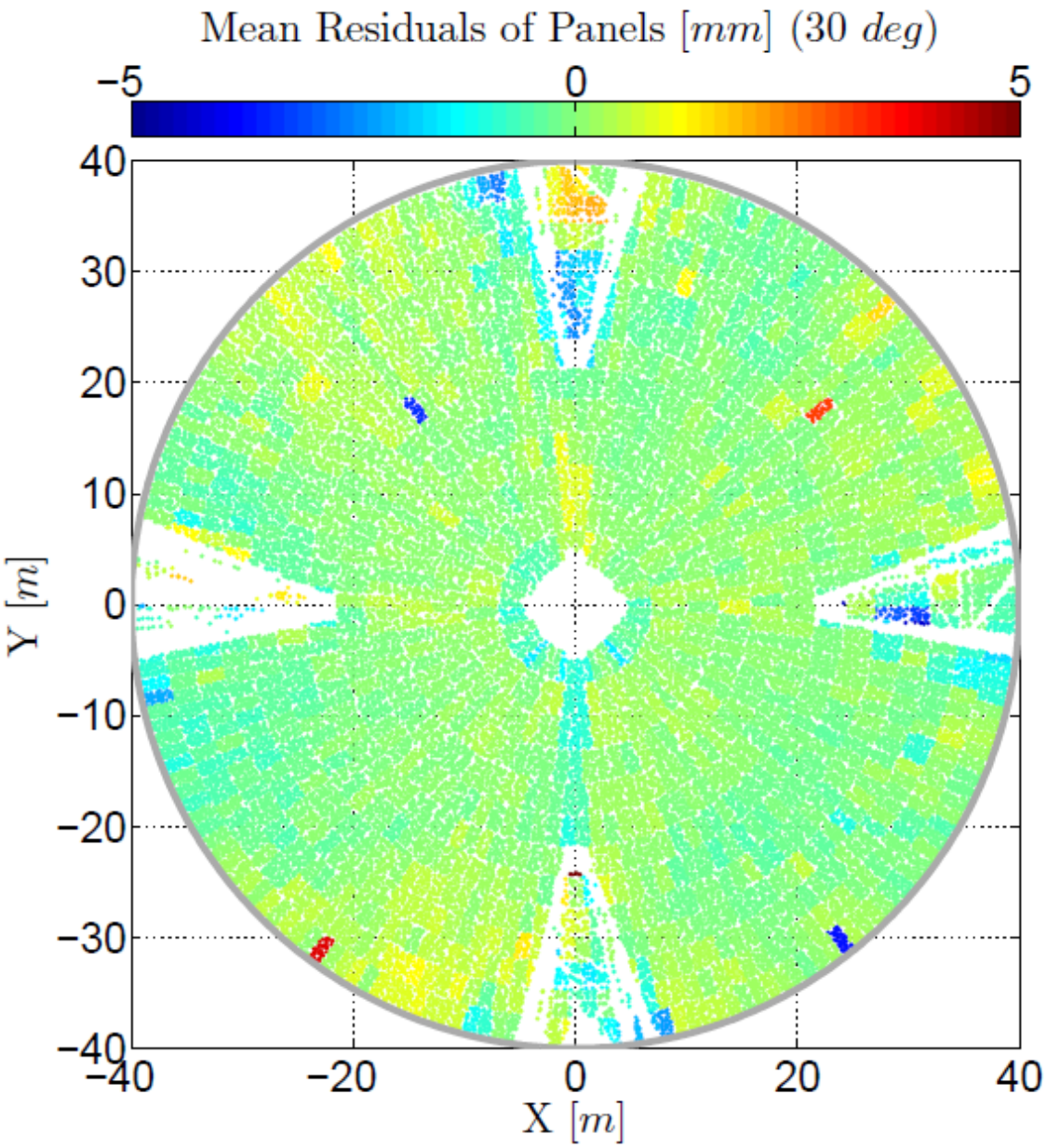
Panel 60

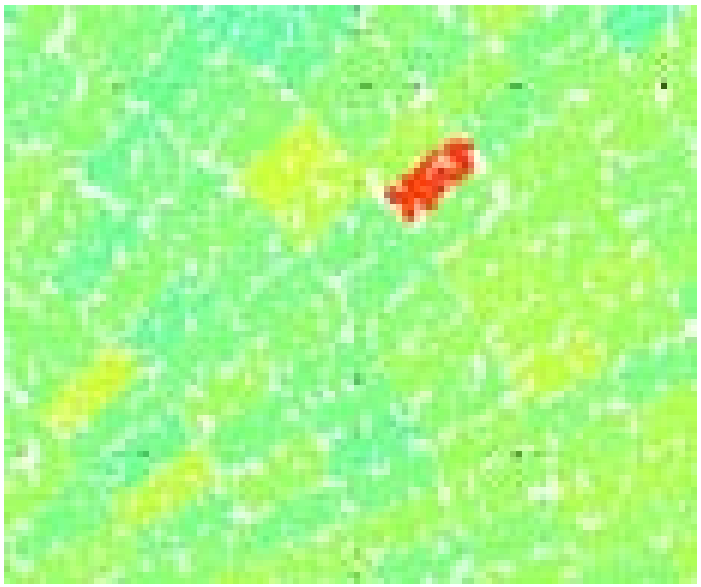


Panel 800

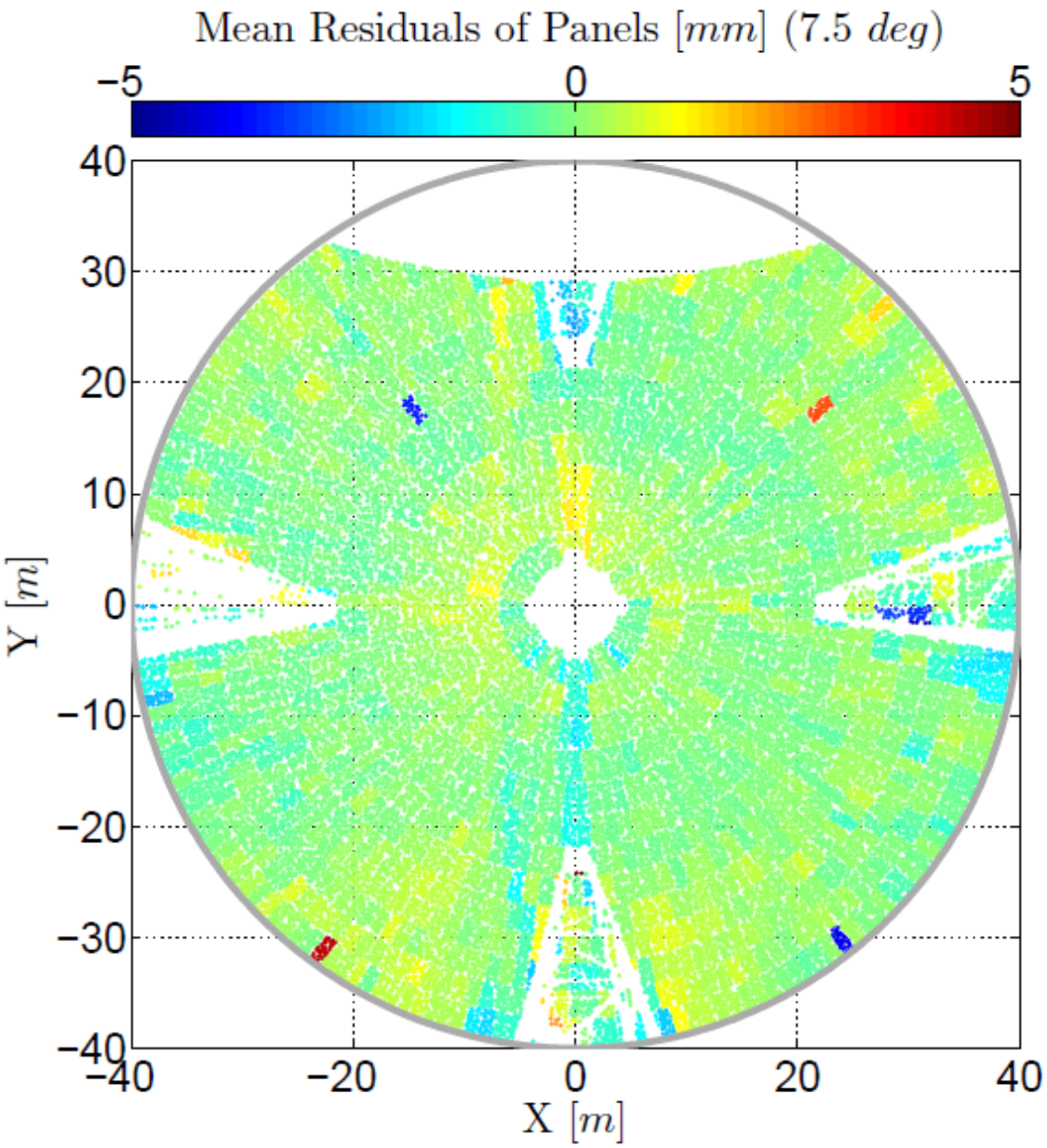


Panel segmentation

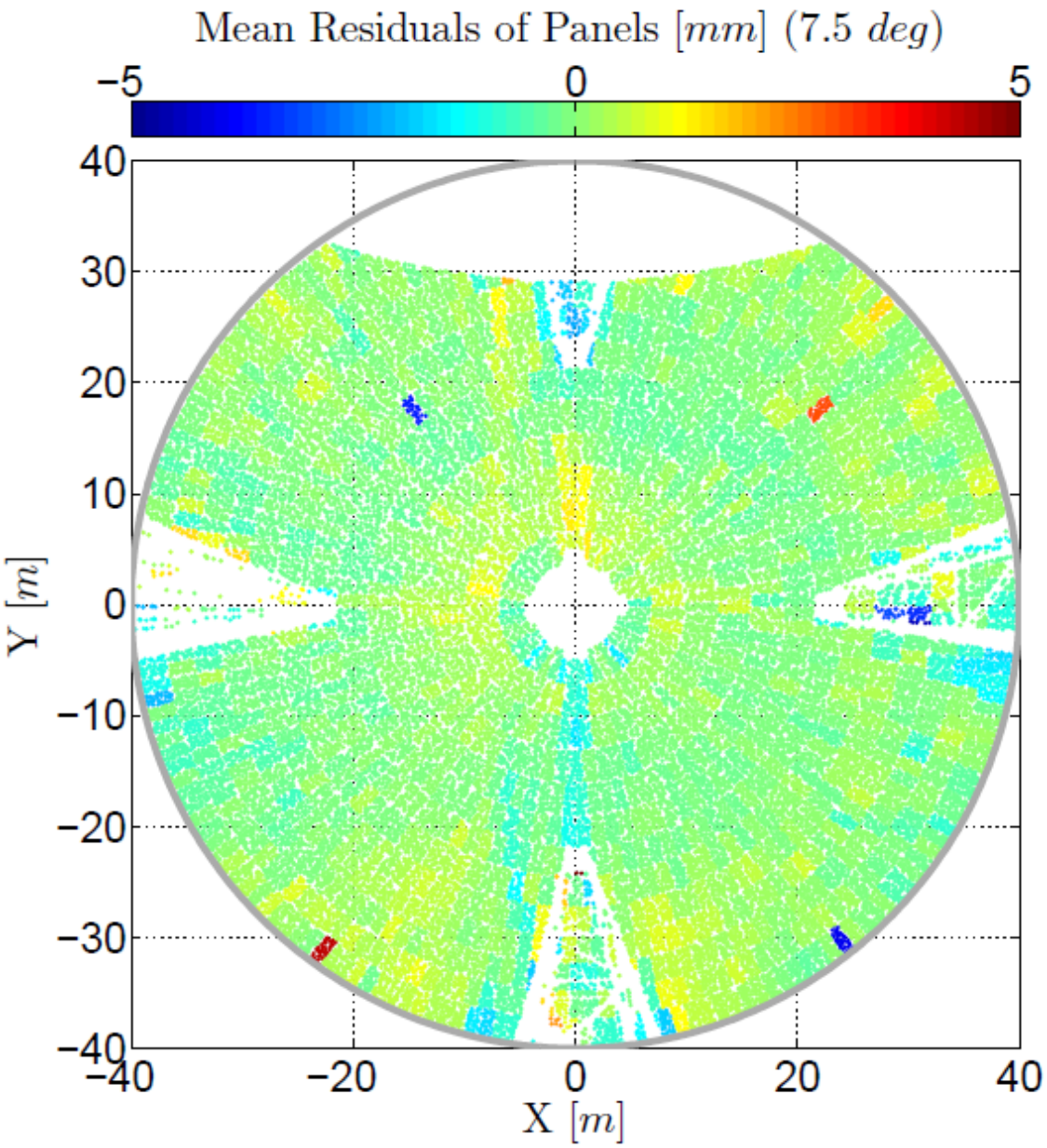


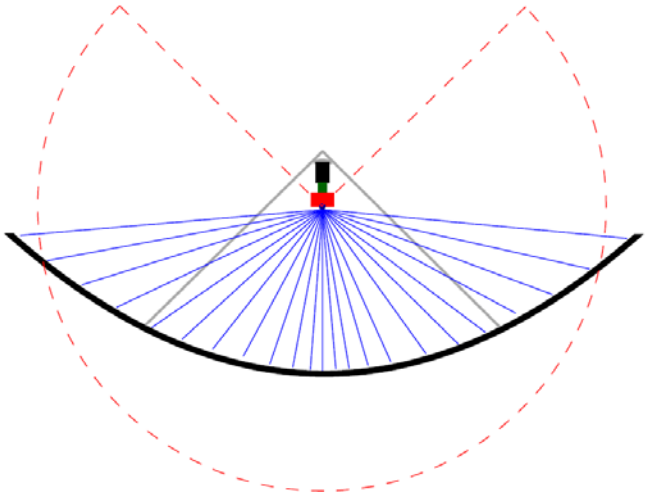


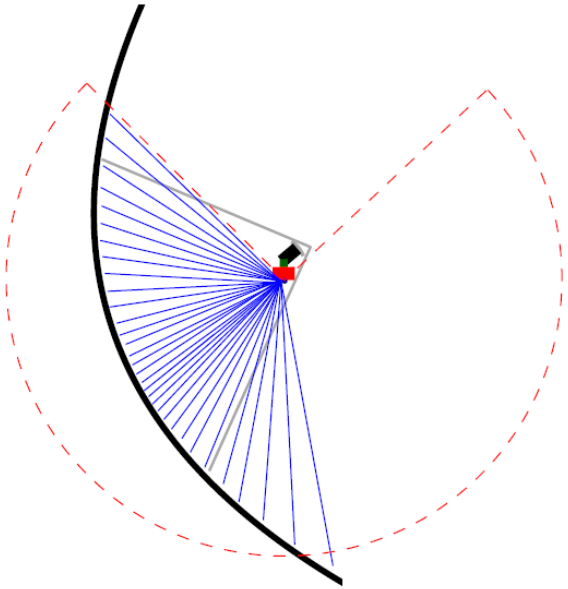
Panels at 7.5° elevation



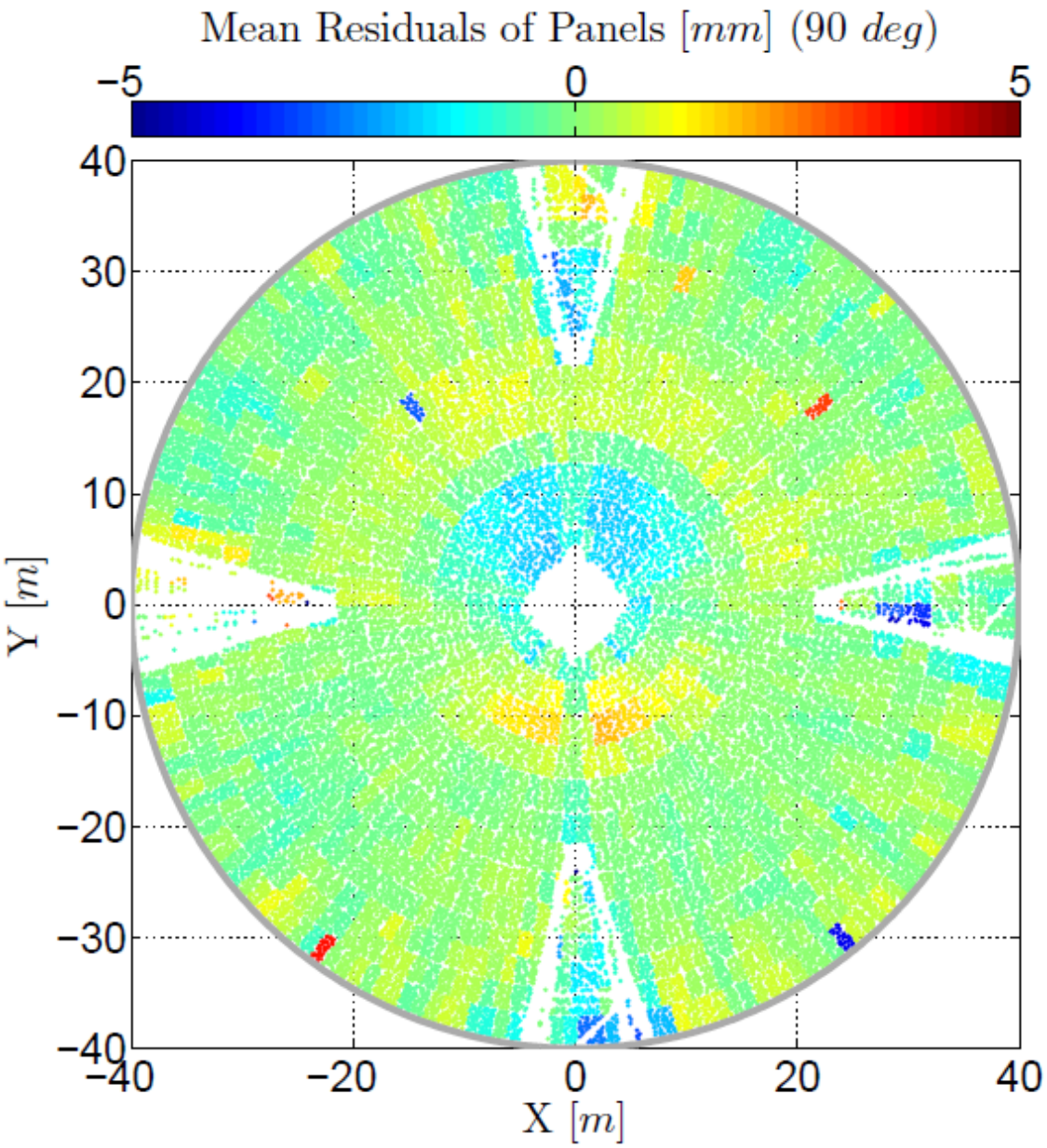
Panels at 7.5° elevation







Panels at 90° elevation



Summary and Conclusions

- Terrestrial laser scanning has potential for detecting telescope deformations
- Terrestrial laser scanners (TLS) have dominant systematic errors, which need to be calibrated/corrected for
- Position of TLS is important (near primary focus)
- Data analysis for radio telescopes requires sophisticated pre-processing steps